

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
13 September 2001 (13.09.2001)

PCT

(10) International Publication Number
WO 01/67659 A1

(51) International Patent Classification⁷: **H04J 14/00**,
14/02, G02B 6/28, H01S 3/00, H04B 10/12, 14/00, G02F
1/39

(74) Agents: **ANDERSON, Thomas, E.** et al.; Hunton &
Williams, 1900 K Street, N.W., Washington, DC 20006
(US).

(21) International Application Number: PCT/US01/07034

(22) International Filing Date: 6 March 2001 (06.03.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/287,101 6 March 2000 (06.03.2000) US

(71) Applicant: **LIGHTCHIP, INC.** [US/US]; 27 Northwest-
ern Drive, Salem, NH 03079 (US).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ,
DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR,
HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR,
LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ,
NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM,
TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

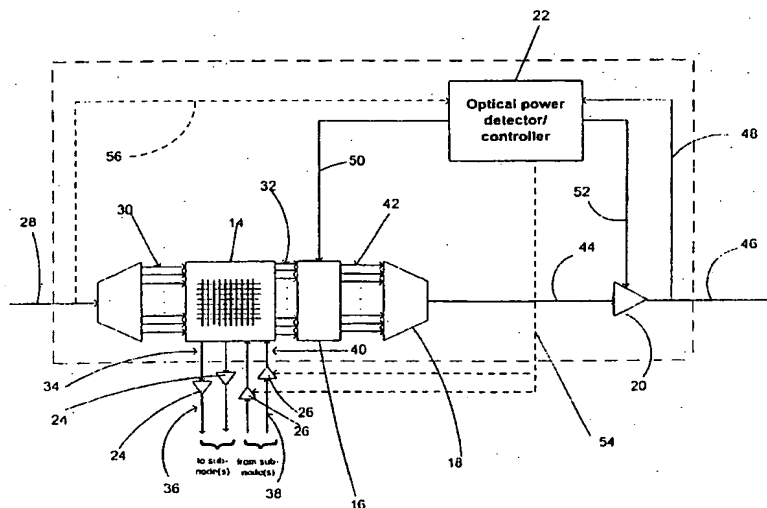
(84) Designated States (*regional*): ARIPO patent (GH, GM,
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian
patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European
patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,
IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,
CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

- with international search report
- before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments

[Continued on next page]

(54) Title: OPTICAL POWER MANAGED NETWORK NODE FOR PROCESSING DENSE WAVELENGTH DIVISION MUL-
TIPLEXED OPTICAL SIGNALS



(57) Abstract: A technique for processing dense wavelength division multiplexed optical signals in a network node (10) is disclosed. In one embodiment, the technique is realized as an optical power managed network node (10) comprising a dense wavelength division multiplexing device (18) for combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal. The optical power managed network node (10) also comprises a wavelength-selective optical power detector (22) for detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal. The optical power managed network node (10) further comprises a plurality of attenuators (16) for attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

WO 01/67659 A1



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

- 1 -

OPTICAL POWER MANAGED NETWORK NODE FOR PROCESSING DENSE WAVELENGTH DIVISION MULTIPLEXED OPTICAL SIGNALS

FIELD OF THE INVENTION

5 The present invention relates generally to dense wavelength division multiplexing networks and, more particularly, to an optical power managed network node for processing dense wavelength division multiplexed optical signals.

BACKGROUND OF THE INVENTION

10 Dense wavelength division multiplexing (DWDM) networks typically comprise a plurality of network nodes for receiving and transmitting dense wavelength division multiplexed optical signals. Each of the plurality of network nodes typically allows an individual optical signal that is contained in a received dense wavelength division multiplexed optical signal to either simply pass through the
15 network node and then be transmitted further along the network from the network node, or be "dropped" at the network node for use by one or more sub-nodes connected to the network node. Each of the plurality of network nodes also typically allows one or more individual optical signals to be "added" to the network at the network node. These "added" optical signals are typically transmitted further along
20 the network from the network node along with other optical signals that are received at the network node, but are not "dropped" at the network node. The above-described network node is generally referred to as an optical add/drop network node due to the "adding" and "dropping" functions performed by the network node.

 The "adding" and "dropping" functions performed by most existing optical
25 add/drop network nodes typically result in a difference between the power of a dense wavelength division multiplexed optical signal that is received at the optical add/drop network node and the power of a dense wavelength division multiplexed optical signal that is transmitted from the optical add/drop network node. For example, if more optical signals are "dropped" at the optical add/drop network node than are "added" at
30 the optical add/drop network node, then the power of the dense wavelength division multiplexed optical signal that is received at the optical add/drop network node will

- 2 -

typically be more than the power of the dense wavelength division multiplexed optical signal that is transmitted from the optical add/drop network node.

Also, most existing optical add/drop network nodes typically inflict some degree of loss upon the power of the optical signals that are received at each network node. That is, an optical add/drop network node typically receives a dense wavelength division multiplexed optical signal in multiplexed form, and then demultiplexes the received dense wavelength division multiplexed optical signal in order for the individual optical signals that are contained within the received dense wavelength division multiplexed optical signal to be processed by the optical add/drop network node. Also, the processing of the individual optical signals at an optical add/drop network node typically comprises switching the individual optical signals such that the individual optical signals are either passed through the optical add/drop network node or "dropped" at the optical add/drop network node. Further, the individual optical signals that are passed through the optical add/drop network node are recombined (i.e., multiplexed) prior to being transmitted further along the network from the optical add/drop network node. All of the above-described demultiplexing, switching, and multiplexing functions typically inflict some degree of loss upon the power of the optical signals that are received at the optical add/drop network node.

The above-described multiplexing function losses that are inflicted upon the power of the optical signals that are received at the optical add/drop network node are also typically inflicted upon the power of any optical signals that are "added" to the network at the optical add/drop network node. That is, optical signals that are "added" to the network at the optical add/drop network node are combined (i.e., multiplexed) with optical signals that are otherwise received at the optical add/drop network node, and a resulting dense wavelength division multiplexed optical signal is transmitted further along the network from the optical add/drop network node. Thus, optical signals that are "added" to the network at the optical add/drop network node are also typically subject to multiplexing function losses.

Furthermore, optical signals that are "added" to a network at most existing optical add/drop network nodes typically have a power level that is different from the optical signals that are otherwise received at the optical add/drop network node. This

- 3 -

5 difference in power between "added" optical signals and optical signals that are otherwise received at the optical add/drop network node typically effects the power of the resulting dense wavelength division multiplexed optical signal that is transmitted further along the network from the optical add/drop network node. For example, if the power of "added" optical signals is greater than the power of optical signals that are otherwise received at the optical add/drop network node, then the power of the resulting dense wavelength division multiplexed optical signal that is transmitted further along the network from the optical add/drop network node is typically greater than the power of the dense wavelength division multiplexed optical signal that is initially received at the optical add/drop network node.

10 Additionally, differences in power between "added" optical signals and optical signals that are otherwise received at most existing optical add/drop network nodes can cause problems such as, for example, channel crosstalk, in the resulting dense wavelength division multiplexed optical signal that is transmitted further along the network from the optical add/drop network node. That is, when "added" optical signals are combined (i.e., multiplexed) with optical signals that are otherwise received at the optical add/drop network node, the higher power optical signals often interfere with the lower power optical signals.

20 All of the above-described power related problems associated with existing optical add/drop network nodes require an operator of a network to continually perform some type of manual network initialization procedure whenever additional optical signals are added to the network, existing optical signals are dropped from the network, or the network is otherwise reconfigured in some manner (e.g., an additional optical add/drop network node is added to the network, an existing optical add/drop network node is removed from the network, etc.). That is, a network operator typically has to perform such a manual network initialization procedure whenever a change occurs in the network such that there is a corresponding change in the power of a dense wavelength division multiplexed optical signal that is transmitted from an optical add/drop network node. Such a change in the power of a dense wavelength division multiplexed optical signal that is transmitted from an optical add/drop network node is seen at every subsequent optical add/drop network node that receives

30

- 4 -

this same dense wavelength division multiplexed optical signal either directly or after all or a portion of this same dense wavelength division multiplexed optical signal propagates through one or more subsequent optical add/drop network nodes. Thus, a network operator typically has to perform a manual network initialization procedure
5 on most, if not all, optical add/drop network nodes in the network so that these optical add/drop network nodes can accommodate the change in the power of every received dense wavelength division multiplexed optical signal.

Obviously, the above-described manual network initialization procedure can be costly in terms of both time spent by a network operator and the cost of optical
10 power measurement and adjustment equipment. Thus, it would be desirable to provide a technique for overcoming the above-described inadequacies and shortcomings of existing optical add/drop network nodes. More particularly, it would be desirable to provide an optical power managed network node for processing dense wavelength division multiplexed optical signals in an efficient and cost effective
15 manner.

OBJECTS OF THE INVENTION

The primary object of the present invention is to provide an optical power managed network node for processing dense wavelength division multiplexed optical
20 signals in an efficient and cost effective manner.

The above-stated primary object, as well as other objects, features, and advantages, of the present invention will become readily apparent to those of ordinary skill in the art from the following summary and detailed descriptions, as well as the appended drawings. While the present invention is described below with reference to
25 preferred embodiment(s), it should be understood that the present invention is not limited thereto. Those of ordinary skill in the art having access to the teachings herein will recognize additional implementations, modifications, and embodiments, as well as other fields of use, which are within the scope of the present invention as disclosed and claimed herein, and with respect to which the present invention could be of
30 significant utility.

SUMMARY OF THE INVENTION

According to the present invention, a technique for processing dense wavelength division multiplexed optical signals in a network node is provided. In a first embodiment, the technique is realized as an optical power managed network node comprising a dense wavelength division multiplexing device for combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal. The optical power managed network node also comprises a wavelength-selective optical power detector for detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal. The optical power managed network node further comprises a plurality of attenuators for attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals. The plurality of narrowband optical signals are beneficially attenuated, prior to being combined into the multiplexed polychromatic optical signal, so as to equalize the power in each of the plurality of narrowband optical signals.

In accordance with other aspects of the present invention, the optical power managed network node further beneficially comprises an adjustable optical power amplifier for adjustably amplifying the power of the multiplexed polychromatic optical signal based upon the detected power of each of the plurality of narrowband optical signals.

In accordance with further aspects of the present invention, the plurality of narrowband optical signals is preferably a first plurality of narrowband optical signals, and the optical power managed network node further beneficially comprises a switching device for switching a second plurality of narrowband optical signals according to a predetermined signal routing scheme, wherein the second plurality of narrowband optical signals constitutes at least a portion of the first plurality of narrowband optical signals. The second plurality of narrowband optical signals are beneficially switched such that the second plurality of narrowband optical signals are routed to either a local sub-node or through the optical power managed network node.

- 6 -

In accordance with still further aspects of the present invention, the switching device beneficially receives at least one of a third plurality of narrowband optical signals for routing through the optical power managed network node. The first plurality of narrowband optical signals beneficially comprises those of the second plurality of narrowband optical signals and the third plurality of narrowband optical signals that are routed through the optical power managed network node.

In accordance with still further aspects of the present invention, the optical power managed network node further beneficially comprises a controller for controlling the power of at least one of the third plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

In accordance with still further aspects of the present invention, the multiplexed polychromatic optical signal is preferably a first multiplexed polychromatic optical signal, and the optical power managed network node further beneficially comprises a demultiplexing device for separating a second multiplexed polychromatic optical signal into the second plurality of narrowband optical signals. The wavelength-selective optical power detector may beneficially detect the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal. Alternatively, the optical power managed network node may further beneficially comprise a second wavelength-selective optical power detector for detecting the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

In an alternative embodiment, the technique is realized as a method for processing dense wavelength division multiplexed signals in an optical power managed network node. The method comprises combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal, and then detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal. The method also comprises attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals. As in the first embodiment of the optical power managed network node described above, the

- 7 -

plurality of narrowband optical signals are beneficially attenuated, prior to being combined into the multiplexed polychromatic optical signal, so as to equalize the power in each of the plurality of narrowband optical signals.

5 In accordance with other aspects of the present invention, the power of the multiplexed polychromatic optical signal is beneficially adjustably amplified based upon the detected power of each of the plurality of narrowband optical signals.

10 In accordance with further aspects of the present invention, the plurality of narrowband optical signals is preferably a first plurality of narrowband optical signals, and a second plurality of narrowband optical signals is beneficially switched according to a predetermined signal routing scheme, wherein the second plurality of narrowband optical signals constitutes at least a portion of the first plurality of narrowband optical signals. Again, the second plurality of narrowband optical signals are beneficially switched such that the second plurality of narrowband optical signals are routed to either a local sub-node or through the optical power managed network node.

15 In accordance with still further aspects of the present invention, at least one of a third plurality of narrowband optical signals is beneficially received for routing through the optical power managed network node. Again, the first plurality of narrowband optical signals beneficially comprises those of the second plurality of narrowband optical signals and the third plurality of narrowband optical signals that are routed through the optical power managed network node.

20 In accordance with still further aspects of the present invention, the power of at least one of the third plurality of narrowband optical signals is beneficially controlled based upon the detected power of each of the plurality of narrowband optical signals.

25 In accordance with still further aspects of the present invention, the multiplexed polychromatic optical signal is preferably a first multiplexed polychromatic optical signal, and a second multiplexed polychromatic optical signal is beneficially separated into the second plurality of narrowband optical signals. The power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal can be beneficially detected

30

- 8 -

either separately or along with the power of each of the first plurality of narrowband optical signals.

The present invention will now be described in more detail with reference to exemplary embodiments thereof as shown in the appended drawings.

5

BRIEF DESCRIPTION OF THE DRAWINGS

In order to facilitate a fuller understanding of the present invention, reference is now made to the appended drawings. These drawings should not be construed as limiting the present invention, but are intended to be exemplary only.

10

Figure 1 is a schematic diagram of a preferred embodiment of an optical power managed network node for processing dense wavelength division multiplexed optical signals in accordance with the present invention.

Figure 2 is a schematic diagram of a preferred embodiment of an optical wavelength control technique in accordance with the present invention.

15

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENT(S)

Referring to Figure 1, there is shown a schematic diagram of a preferred embodiment of an optical power managed network node 10 for processing dense wavelength division multiplexed optical signals in accordance with the present invention. The optical power managed network node 10 comprises a demultiplexing device 12, a switching device 14, a plurality of variable optical attenuators 16, a multiplexing device 18, a variable optical amplifier or gain element 20, a wavelength-selective optical power detector/controller 22, a first plurality of optical receivers/transmitters 24, and a second plurality of optical transmitters/receivers 26. The optical power managed network node 10 operates, through its aforementioned constituent parts, as follows.

25

30

The demultiplexing device 12 receives a first dense wavelength division multiplexed (DWDM) polychromatic optical signal on an optical input fiber 28. The first DWDM polychromatic optical signal contains a first plurality of narrowband optical signals, each carrying a unique channel of transmitted data. The demultiplexing device 12 separates the first DWDM polychromatic optical signal into

the first plurality of narrowband optical signals contained therein and forwards each of the first plurality of narrowband optical signals to the switching device 14 along a corresponding plurality of optical fibers 30.

5 The switching device 14 switches the first plurality of narrowband optical signals according to some signal routing scheme. That is, each of the first plurality of narrowband optical signals either pass through the switching device 14 so as to be output from the switching device 14 on one of a plurality of optical fibers 32, or are “dropped” by the optical power managed network node 10, and hence from the network to which the optical power managed network node 10 is connected. Those
10 narrowband optical signals that are “dropped” by the optical power managed network node 10 are output from the switching device 14 on optical fibers 34, which are connected to the first plurality of optical receivers/transmitters 24. The first plurality of optical receivers/transmitters 24 transmit the narrowband optical signals received on optical fibers 34 to one or more sub-nodes (not shown) via output optical fibers 36.
15 Of course, the optical fibers 34 that carry the narrowband optical signals from the optical power managed network node 10 could extend all the way to the one or more sub-nodes (not shown), thereby alleviating the need for the first plurality of optical receivers/transmitters 24.

20 The second plurality of optical receivers/transmitters 26 may or may not be connected to the same sub-nodes as the first plurality of optical receivers/transmitters 24. In any event, the second plurality of optical receivers/transmitters 26 receive narrowband optical signals from one or more sub-nodes (not shown) on input optical fibers 38. The second plurality of optical receivers/transmitters 26 transmit the narrowband optical signals received on input optical fibers 38 to the switching device
25 14 via optical fibers 40. Of course, as with the optical fibers 34 that carry the narrowband optical signals from the optical power managed network node 10, the optical fibers 40 that carry the narrowband optical signals to the optical power managed network node 10 could extend all the way from the one or more sub-nodes (not shown), thereby alleviating the need for the second plurality of optical
30 receivers/transmitters 26.

- 10 -

The switching device 14 "adds" the narrowband optical signals received on optical fibers 40 to the network to which the optical power managed network node 10 is connected. That is, the switching device 14 includes the narrowband optical signals received on optical fibers 40 with those narrowband optical signals from the first plurality of narrowband optical signals that pass through the switching device 14 and are output from the switching device 14 on one of the plurality of optical fibers 32. Thus, the plurality of optical fibers 32 carry a second plurality of narrowband optical signals comprised of the narrowband optical signals from the first plurality of narrowband optical signals that pass through the switching device 14 (i.e., those of the first plurality of narrowband optical signals that are not "dropped" by the optical power managed network node 10), as well as the "added" narrowband optical signals received at the switching device 14 on optical fibers 40.

At this point it should be noted that the switching device 14 can be, for example, a switch matrix or some other type of fixed or dynamic optical signal switching element.

The plurality of optical fibers 32 carry the second plurality of narrowband optical signals to the plurality of variable optical attenuators 16. As described in more detail below, the plurality of variable optical attenuators 16 act to equalize the power level of each of the second plurality of narrowband optical signals based upon the detected power level of each of the second plurality of narrowband optical signals after they have been multiplexed by the multiplexing device 18 and amplified by the variable optical amplifier or gain element 20. Thus, at this point, suffice it to say that the plurality of variable optical attenuators 16 act to equalize the power level of each of the second plurality of narrowband optical signals prior to being multiplexed by the multiplexing device 18. The plurality of variable optical attenuators 16 thus provide an attenuated version of the second plurality of narrowband optical signals to the multiplexing device 18 via a plurality of optical fibers 42.

As mentioned above, the multiplexing device 18 combines the attenuated version of the second plurality of narrowband optical signals into a second dense wavelength division multiplexed (DWDM) polychromatic optical signal and forwards this second DWDM polychromatic optical signal to the variable optical amplifier or

- 11 -

gain element 20 on an optical output fiber 44. As described in more detail below, the variable optical amplifier or gain element 20 amplifies this second DWDM polychromatic optical signal based upon the detected power level of each of the second plurality of narrowband optical signals contained in the second DWDM polychromatic optical signal (i.e., after attenuation by the plurality of variable optical attenuators 16 and multiplexing by the multiplexing device 18). The variable optical amplifier or gain element 20 thus provides an amplified version of the second DWDM polychromatic optical signal on output optical fiber 46. At this point it should be noted that the variable optical amplifier or gain element 20 could be, for example, an erbium doped fiber amplifier (EDFA), an erbium doped waveguide amplifier (EDWA), a Raman amplifier, or some other type of variable optical amplifier or gain element.

The wavelength-selective optical power detector/controller 22 taps a portion of the amplified version of the second DWDM polychromatic optical signal being carried on output optical fiber 46 via an optical tap fiber 48 so as to detect the power level of each of the second plurality of narrowband optical signals contained in the second DWDM polychromatic optical signal (i.e., after attenuation by the plurality of variable optical attenuators 16 and multiplexing by the multiplexing device 18). One technique for accomplishing this power detection function is described in related U.S. Patent Application No. 09/578,721, filed May 26, 2000, which has previously been incorporated by reference herein in its entirety.

After determining the power level of each of the second plurality of narrowband optical signals contained in the second DWDM polychromatic optical signal (i.e., after attenuation by the plurality of variable optical attenuators 16 and multiplexing by the multiplexing device 18), the wavelength-selective optical power detector/controller 22 provides one or more first power control signals to the plurality of variable optical attenuators 16 on a first power control signal line/bus 50, and provides a second power control signal to the variable optical amplifier or gain element 20 on a second power control signal line/bus 52. These first and second power control signals allow the power level of the amplified version of the second DWDM polychromatic optical signal on output optical fiber 46 to be controlled such

- 12 -

that the amplified version of the second DWDM polychromatic optical signal on output optical fiber 46 is always at a constant power level. Thus, the optical power managed network node 10 always provides a constant power level DWDM polychromatic optical output signal. This constant power level DWDM polychromatic optical output signal provided by the optical power managed network node 10 is probably most beneficial when it matches the power level of the first DWDM polychromatic optical signal on the optical input fiber 28, thereby resulting in the optical power managed network node 10 having a zero decibel (dB) level loss. Thus, the present invention optical power managed network node 10 alleviates the need for manual network initialization procedures whenever additional optical signals are added to a network, existing optical signals are dropped from a network, or a network is otherwise reconfigured in some manner (e.g., an additional optical add/drop network node is added to a network, an existing optical add/drop network node is removed from a network, etc.).

At this point it should be noted that the wavelength-selective optical power detector/controller 22 may also provide a third power control signal to the second plurality of optical receivers/transmitters 26 on a third power control signal line/bus 54 so as to control the power level of the second plurality of optical receivers/transmitters 26 which transmit the narrowband optical signals received on input optical fibers 38 to the switching device 14 via optical fibers 40. This additional aspect of power level control in accordance with the present invention may be beneficial in that the second plurality of optical receivers/transmitters 26 may be of a lower power variety, thereby requiring less cost.

At this point it should be noted that the wavelength-selective optical power detector/controller 22 may also tap a portion of the first DWDM polychromatic optical signal being carried on optical input fiber 28 via an optical tap fiber 56 so as to detect the power level of each of the first plurality of narrowband optical signals contained in the first DWDM polychromatic optical signal. This additional aspect of power level control in accordance with the present invention may be beneficial in that the power level of each of the first plurality of narrowband optical signals contained in the first

- 13 -

DWDM polychromatic optical signal may be detected so as to determine if any failures have occurred in the network.

Referring to Figure 2, there is shown a schematic diagram of a preferred embodiment of an optical wavelength control system 60 in accordance with the present invention. The optical wavelength control system 60 comprises a central office 62, an optical cross-connect 64, an optical wavelength monitor 66, and a laser locking device 68. The optical wavelength control system 60 operates, through its aforementioned constituent parts, as follows.

The central office 62 receives and transmits a plurality of narrowband optical signals from and to the optical cross-connect via a plurality of optical fibers 76. The plurality of optical fibers 76 connect to a plurality of multiplexing/demultiplexing devices within the optical cross-connect 64. That is, the optical cross-connect 64 includes a first multiplexing/demultiplexing device 70, a second multiplexing/demultiplexing device 72, and a third multiplexing/demultiplexing device 74, each for receiving and transmitting the plurality of narrowband optical signals from and to the central office 62 via the plurality of optical fibers 76. The plurality of multiplexing/demultiplexing devices 70, 72, 74 within the optical cross-connect 64 perform multiplexing functions on the plurality of narrowband optical signals received from the central office 62 so as to generate dense wavelength division multiplexed (DWDM) polychromatic optical signals transmitted on optical fibers 78, 80, 82, respectively. The plurality of multiplexing/demultiplexing devices 70, 72, 74 within the optical cross-connect 64 also perform demultiplexing functions on DWDM polychromatic optical signals received on optical fibers 78, 80, 82, respectively, so as to generate the plurality of narrowband optical signals transmitted to the central office 62.

Similar to the wavelength-selective optical power detector/controller 22 of Figure 1, the optical wavelength monitor 66 of Figure 2 taps a portion of the DWDM polychromatic optical signals being carried on each of the optical fibers 78, 80, 82 via optical tap fibers 84, 86, 88, respectively, so as to detect the wavelength of each of the plurality of narrowband optical signals contained in all of the DWDM polychromatic optical signals. One technique for accomplishing this wavelength monitoring function

is described in related U.S. Patent Application No. 09/578,721, filed May 26, 2000, which has previously been incorporated by reference herein in its entirety.

5 The optical wavelength monitor 66 provides an indication of the wavelength of each of the plurality of narrowband optical signals contained in all of the DWDM polychromatic optical signals to the laser locking device 68 via one or more wavelength indicator lines 90. The laser locking device 68 in turn provides one or more laser control signals to the central office 62 via laser control lines 92. These laser control signals provide a mechanism for controlling the accuracy of the wavelengths of each of the plurality of narrowband optical signals transmitted from
10 the central office 62. Thus, the optical wavelength control system 60 insures that wavelength accuracy is maintained within the system.

The present invention is not to be limited in scope by the specific embodiments described herein. Indeed, various modifications of the present invention, in addition to those described herein, will be apparent to those of ordinary skill in the art from the foregoing description and accompanying drawings. Thus,
15 such modifications are intended to fall within the scope of the following appended claims. Further, although the present invention has been described herein in the context of a particular implementation in a particular environment for a particular purpose, those of ordinary skill in the art will recognize that its usefulness is not limited thereto and that the present invention can be beneficially implemented in any
20 number of environments for any number of purposes. Accordingly, the claims set forth below should be construed in view of the full breath and spirit of the present invention as disclosed herein.

CLAIMS

What is claimed is:

1. An optical power managed network node for processing dense wavelength division multiplexed signals comprising:
 - 5 a dense wavelength division multiplexing device for combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal;
 - a wavelength-selective optical power detector for detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal; and
 - 10 a plurality of attenuators for attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.
2. The optical power managed network node as defined in claim 1, further comprising:
 - 15 an adjustable power amplifier for adjustably amplifying the power of the multiplexed polychromatic optical signal based upon the detected power of each of the plurality of narrowband optical signals.
3. The optical power managed network node as defined in claim 1, wherein the at least one of the plurality of narrowband optical signals is attenuated so as to equalize the power in each of the plurality of narrowband optical signals.
4. The optical power managed network node as defined in claim 1, wherein the at least one of the plurality of narrowband optical signals is attenuated prior to being combined into the multiplexed polychromatic optical signal.
5. The optical power managed network node as defined in claim 1, wherein the plurality of narrowband optical signals is a first plurality of narrowband optical signals, further comprising:
 - 25 a switching device for switching a second plurality of narrowband optical signals according to a predetermined signal routing scheme, wherein the second plurality of narrowband optical signals constitutes at least a portion of the first
 - 30 plurality of narrowband optical signals.

6. The optical power managed network node as defined in claim 5, wherein at least one of the second plurality of narrowband optical signals is switched such that the at least one switched narrowband optical signal is routed to a local sub-node.

5 7. The optical power managed network node as defined in claim 5, wherein at least one of the second plurality of narrowband optical signals is switched such that the at least one switched narrowband optical signal is routed through the optical power managed network node.

8. The optical power managed network node as defined in claim 7, wherein the switching device receives at least one of a third plurality of narrowband optical signals for routing through the optical power managed network node.

9. The optical power managed network node as defined in claim 8, wherein the first plurality of narrowband optical signals comprises those of the second plurality of narrowband optical signals and the third plurality of narrowband optical signals that are routed through the optical power managed network node.

10. The optical power managed network node as defined in claim 8, further comprising:

a controller for controlling the power of the at least one of the third plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

11. The optical power managed network node as defined in claim 5, wherein the multiplexed polychromatic optical signal is a first multiplexed polychromatic optical signal, further comprising:

a demultiplexing device for separating a second multiplexed polychromatic optical signal into the second plurality of narrowband optical signals.

12. The optical power managed network node as defined in claim 11, wherein the wavelength-selective optical power detector also detects the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

13. The optical power managed network node as defined in claim 11, wherein the wavelength-selective optical power detector is a first wavelength-selective optical power detector, further comprising:

5 a second wavelength-selective optical power detector for detecting the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

14. A method for processing dense wavelength division multiplexed signals in an optical power managed network node, the method comprising the steps of:

10 combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal;

detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal; and

15 attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

15. The method as defined in claim 14, further comprising the step of:
adjustably amplifying the power of the multiplexed polychromatic optical signal based upon the detected power of each of the plurality of narrowband optical signals.
20

16. The method as defined in claim 14, wherein the at least one of the plurality of narrowband optical signals is attenuated so as to equalize the power in each of the plurality of narrowband optical signals.

17. The method as defined in claim 14, wherein the at least one of the plurality of narrowband optical signals is attenuated prior to being combined into the multiplexed polychromatic optical signal.
25

18. The method as defined in claim 14, wherein the plurality of narrowband optical signals is a first plurality of narrowband optical signals, further comprising the step of:

30 switching a second plurality of narrowband optical signals according to a predetermined signal routing scheme, wherein the second plurality of narrowband

- 18 -

optical signals constitutes at least a portion of the first plurality of narrowband optical signals.

19. The method as defined in claim 18, wherein at least one of the second plurality of narrowband optical signals is switched such that the at least one switched narrowband optical signal is routed to a local sub-node.

20. The method as defined in claim 18, wherein at least one of the second plurality of narrowband optical signals is switched such that the at least one switched narrowband optical signal is routed through the optical power managed network node.

21. The method as defined in claim 20, further comprising the step of:
receiving at least one of a third plurality of narrowband optical signals for routing through the optical power managed network node.

22. The method as defined in claim 21, wherein the first plurality of narrowband optical signals comprises those of the second plurality of narrowband optical signals and the third plurality of narrowband optical signals that are routed through the optical power managed network node.

23. The method as defined in claim 21, further comprising the step of:
controlling the power of the at least one of the third plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

24. The method as defined in claim 18, wherein the multiplexed polychromatic optical signal is a first multiplexed polychromatic optical signal, further comprising the step of:

separating a second multiplexed polychromatic optical signal into the second plurality of narrowband optical signals.

25. The method as defined in claim 24, wherein the step of detecting includes detecting the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

26. The method as defined in claim 24, further comprising the step of:
detecting the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

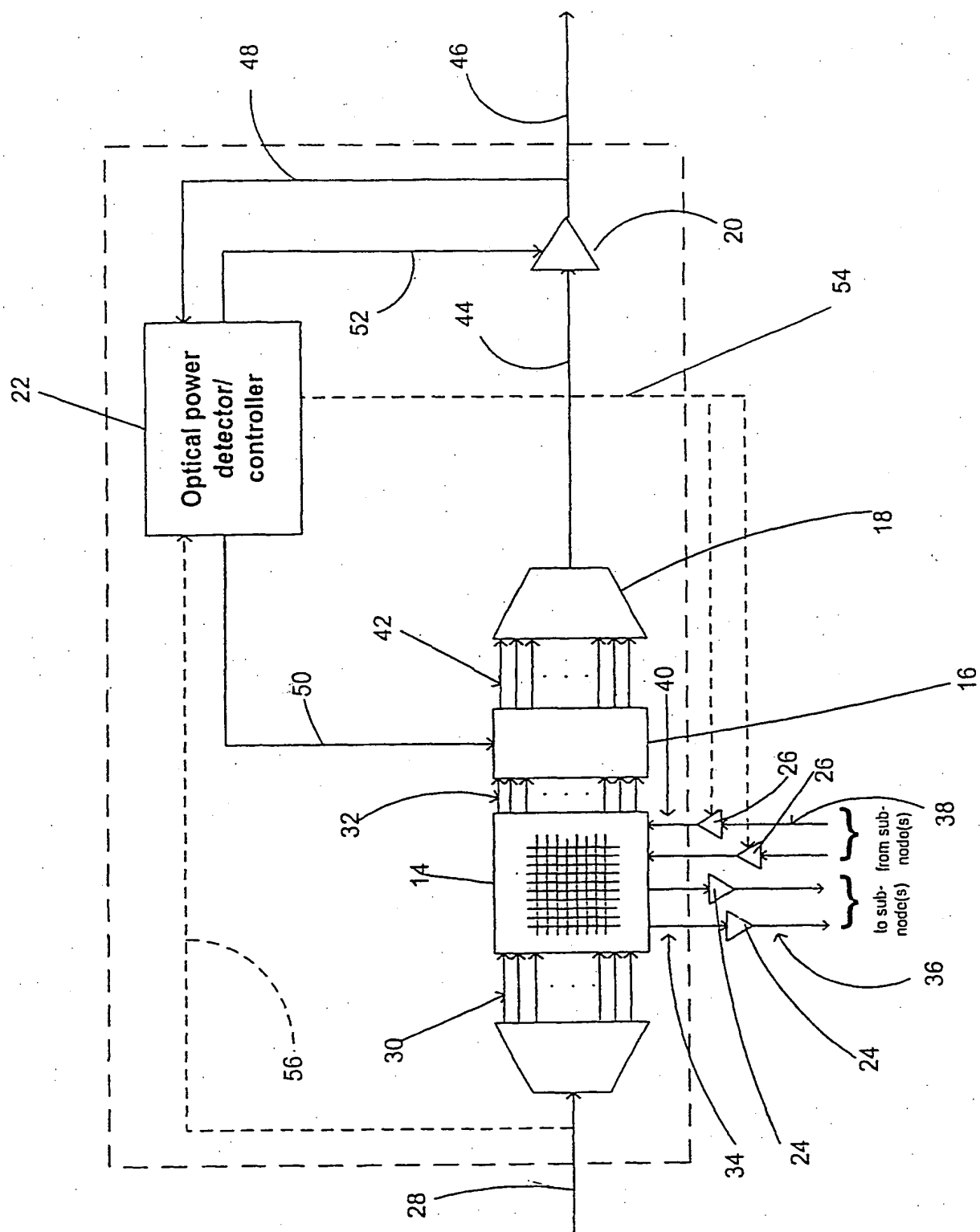


Figure 1

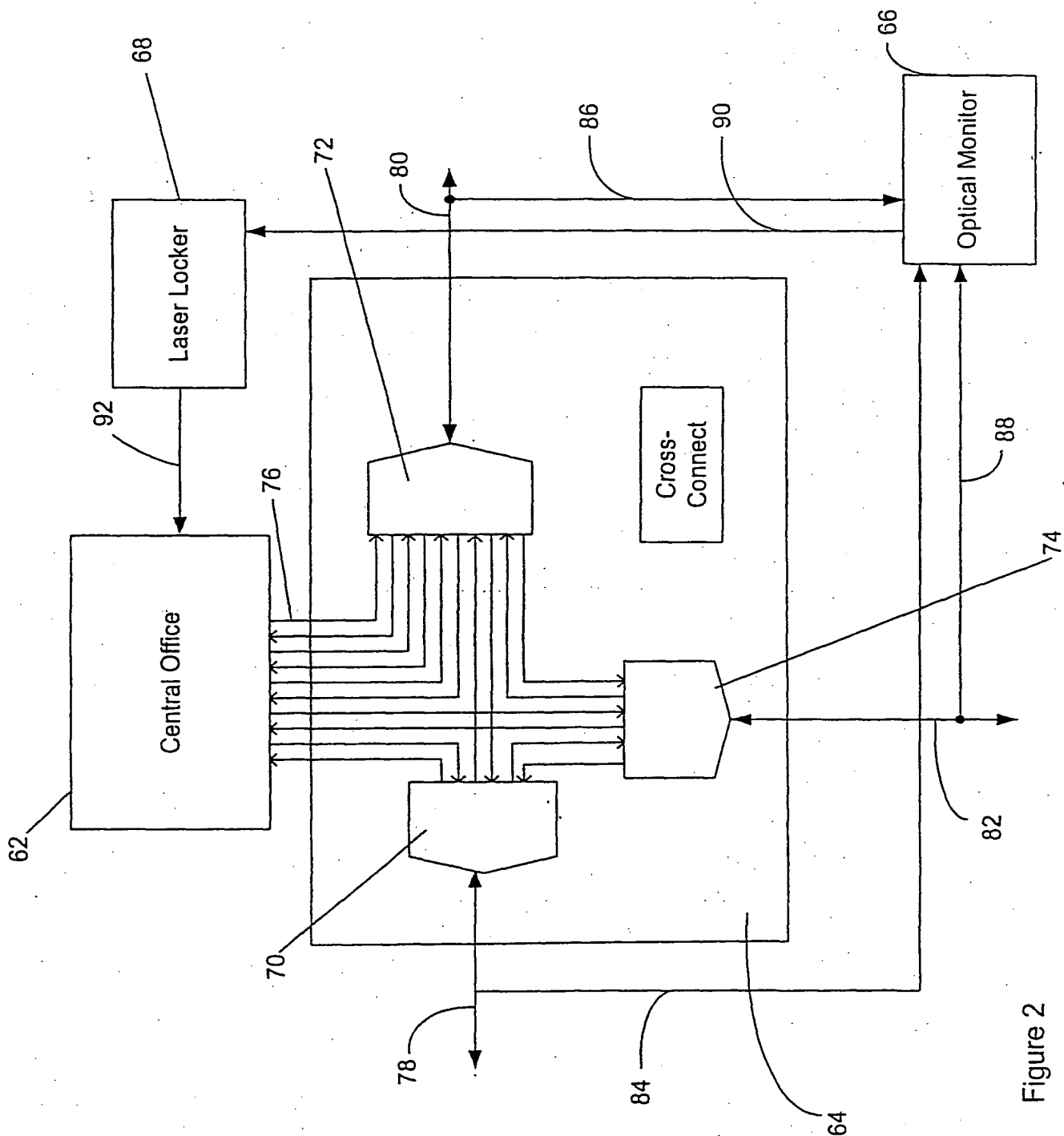


Figure 2

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
13 September 2001 (13.09.2001)

PCT

(10) International Publication Number
WO 01/067659 A1

(51) International Patent Classification⁷: **H04J 14/00**,
14/02, G02B 6/28, H01S 3/00, H04B 10/12, 14/00, G02F
1/39

(74) Agents: **ANDERSON, Thomas, E.** et al.; Hunton &
Williams, 1900 K Street, N.W., Washington, DC 20006
(US).

(21) International Application Number: PCT/US01/07034

(22) International Filing Date: 6 March 2001 (06.03.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/287,101 6 March 2000 (06.03.2000) US

(71) Applicant: **LIGHTCHIP, INC.** [US/US]; 27 Northwest-
ern Drive, Salem, NH 03079 (US).

(72) Inventors: **TURNER, Ian**; 25 Winding Brook Drive,
Stratham, NH 03885 (US). **EMKEY, William, L.**; 67
Searles Road, Windham, NH 03087 (US). **WADE, Robert,
K.**; 2625 NW 31st Street, Boca Raton, FL 33434 (US).

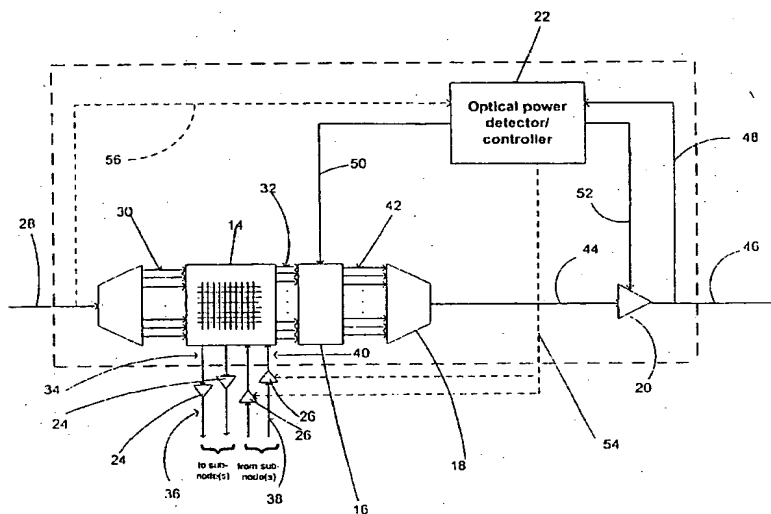
(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ,
DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR,
HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR,
LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ,
NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM,
TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM,
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian
patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European
patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,
IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF,
CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— with international search report

[Continued on next page]

(54) Title: OPTICAL POWER MANAGED NETWORK NODE FOR PROCESSING DENSE WAVELENGTH DIVISION MUL-
TIPLEXED OPTICAL SIGNALS



(57) Abstract: A technique for processing dense wavelength division multiplexed optical signals in a network node (10) is disclosed. In one embodiment, the technique is realized as an optical power managed network node (10) comprising a dense wavelength division multiplexing device (18) for combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal. The optical power managed network node (10) also comprises a wavelength-selective optical power detector (22) for detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal. The optical power managed network node (10) further comprises a plurality of attenuators (16) for attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

WO 01/067659 A1



(48) Date of publication of this corrected version:

27 March 2003

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(15) Information about Correction:

see PCT Gazette No. 13/2003 of 27 March 2003, Section II

OPTICAL POWER MANAGED NETWORK NODE FOR PROCESSING DENSE WAVELENGTH DIVISION MULTIPLEXED OPTICAL SIGNALS

FIELD OF THE INVENTION

5 The present invention relates generally to dense wavelength division multiplexing networks and, more particularly, to an optical power managed network node for processing dense wavelength division multiplexed optical signals.

BACKGROUND OF THE INVENTION

10 Dense wavelength division multiplexing (DWDM) networks typically comprise a plurality of network nodes for receiving and transmitting dense wavelength division multiplexed optical signals. Each of the plurality of network nodes typically allows an individual optical signal that is contained in a received
15 dense wavelength division multiplexed optical signal to either simply pass through the network node and then be transmitted further along the network from the network node, or be "dropped" at the network node for use by one or more sub-nodes connected to the network node. Each of the plurality of network nodes also typically allows one or more individual optical signals to be "added" to the network at the network node. These "added" optical signals are typically transmitted further along
20 the network from the network node along with other optical signals that are received at the network node, but are not "dropped" at the network node. The above-described network node is generally referred to as an optical add/drop network node due to the "adding" and "dropping" functions performed by the network node.

25 The "adding" and "dropping" functions performed by most existing optical add/drop network nodes typically result in a difference between the power of a dense wavelength division multiplexed optical signal that is received at the optical add/drop network node and the power of a dense wavelength division multiplexed optical signal that is transmitted from the optical add/drop network node. For example, if more
30 optical signals are "dropped" at the optical add/drop network node than are "added" at the optical add/drop network node, then the power of the dense wavelength division multiplexed optical signal that is received at the optical add/drop network node will

- 2 -

typically be more than the power of the dense wavelength division multiplexed optical signal that is transmitted from the optical add/drop network node.

Also, most existing optical add/drop network nodes typically inflict some degree of loss upon the power of the optical signals that are received at each network node. That is, an optical add/drop network node typically receives a dense wavelength division multiplexed optical signal in multiplexed form, and then demultiplexes the received dense wavelength division multiplexed optical signal in order for the individual optical signals that are contained within the received dense wavelength division multiplexed optical signal to be processed by the optical add/drop network node. Also, the processing of the individual optical signals at an optical add/drop network node typically comprises switching the individual optical signals such that the individual optical signals are either passed through the optical add/drop network node or "dropped" at the optical add/drop network node. Further, the individual optical signals that are passed through the optical add/drop network node are recombined (i.e., multiplexed) prior to being transmitted further along the network from the optical add/drop network node. All of the above-described demultiplexing, switching, and multiplexing functions typically inflict some degree of loss upon the power of the optical signals that are received at the optical add/drop network node.

The above-described multiplexing function losses that are inflicted upon the power of the optical signals that are received at the optical add/drop network node are also typically inflicted upon the power of any optical signals that are "added" to the network at the optical add/drop network node. That is, optical signals that are "added" to the network at the optical add/drop network node are combined (i.e., multiplexed) with optical signals that are otherwise received at the optical add/drop network node, and a resulting dense wavelength division multiplexed optical signal is transmitted further along the network from the optical add/drop network node. Thus, optical signals that are "added" to the network at the optical add/drop network node are also typically subject to multiplexing function losses.

Furthermore, optical signals that are "added" to a network at most existing optical add/drop network nodes typically have a power level that is different from the optical signals that are otherwise received at the optical add/drop network node. This

difference in power between "added" optical signals and optical signals that are otherwise received at the optical add/drop network node typically effects the power of the resulting dense wavelength division multiplexed optical signal that is transmitted further along the network from the optical add/drop network node. For example, if the power of "added" optical signals is greater than the power of optical signals that are otherwise received at the optical add/drop network node, then the power of the resulting dense wavelength division multiplexed optical signal that is transmitted further along the network from the optical add/drop network node is typically greater than the power of the dense wavelength division multiplexed optical signal that is initially received at the optical add/drop network node.

Additionally, differences in power between "added" optical signals and optical signals that are otherwise received at most existing optical add/drop network nodes can cause problems such as, for example, channel crosstalk, in the resulting dense wavelength division multiplexed optical signal that is transmitted further along the network from the optical add/drop network node. That is, when "added" optical signals are combined (i.e., multiplexed) with optical signals that are otherwise received at the optical add/drop network node, the higher power optical signals often interfere with the lower power optical signals.

All of the above-described power related problems associated with existing optical add/drop network nodes require an operator of a network to continually perform some type of manual network initialization procedure whenever additional optical signals are added to the network, existing optical signals are dropped from the network, or the network is otherwise reconfigured in some manner (e.g., an additional optical add/drop network node is added to the network, an existing optical add/drop network node is removed from the network, etc.). That is, a network operator typically has to perform such a manual network initialization procedure whenever a change occurs in the network such that there is a corresponding change in the power of a dense wavelength division multiplexed optical signal that is transmitted from an optical add/drop network node. Such a change in the power of a dense wavelength division multiplexed optical signal that is transmitted from an optical add/drop network node is seen at every subsequent optical add/drop network node that receives

- 4 -

this same dense wavelength division multiplexed optical signal either directly or after all or a portion of this same dense wavelength division multiplexed optical signal propagates through one or more subsequent optical add/drop network nodes. Thus, a network operator typically has to perform a manual network initialization procedure on most, if not all, optical add/drop network nodes in the network so that these optical add/drop network nodes can accommodate the change in the power of every received dense wavelength division multiplexed optical signal.

Obviously, the above-described manual network initialization procedure can be costly in terms of both time spent by a network operator and the cost of optical power measurement and adjustment equipment. Thus, it would be desirable to provide a technique for overcoming the above-described inadequacies and shortcomings of existing optical add/drop network nodes. More particularly, it would be desirable to provide an optical power managed network node for processing dense wavelength division multiplexed optical signals in an efficient and cost effective manner.

OBJECTS OF THE INVENTION

The primary object of the present invention is to provide an optical power managed network node for processing dense wavelength division multiplexed optical signals in an efficient and cost effective manner.

The above-stated primary object, as well as other objects, features, and advantages, of the present invention will become readily apparent to those of ordinary skill in the art from the following summary and detailed descriptions, as well as the appended drawings. While the present invention is described below with reference to preferred embodiment(s), it should be understood that the present invention is not limited thereto. Those of ordinary skill in the art having access to the teachings herein will recognize additional implementations, modifications, and embodiments, as well as other fields of use, which are within the scope of the present invention as disclosed and claimed herein, and with respect to which the present invention could be of significant utility.

SUMMARY OF THE INVENTION

According to the present invention, a technique for processing dense wavelength division multiplexed optical signals in a network node is provided. In a first embodiment, the technique is realized as an optical power managed network node comprising a dense wavelength division multiplexing device for combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal. The optical power managed network node also comprises a wavelength-selective optical power detector for detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal. The optical power managed network node further comprises a plurality of attenuators for attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals. The plurality of narrowband optical signals are beneficially attenuated, prior to being combined into the multiplexed polychromatic optical signal, so as to equalize the power in each of the plurality of narrowband optical signals.

In accordance with other aspects of the present invention, the optical power managed network node further beneficially comprises an adjustable optical power amplifier for adjustably amplifying the power of the multiplexed polychromatic optical signal based upon the detected power of each of the plurality of narrowband optical signals.

In accordance with further aspects of the present invention, the plurality of narrowband optical signals is preferably a first plurality of narrowband optical signals, and the optical power managed network node further beneficially comprises a switching device for switching a second plurality of narrowband optical signals according to a predetermined signal routing scheme, wherein the second plurality of narrowband optical signals constitutes at least a portion of the first plurality of narrowband optical signals. The second plurality of narrowband optical signals are beneficially switched such that the second plurality of narrowband optical signals are routed to either a local sub-node or through the optical power managed network node.

In accordance with still further aspects of the present invention, the switching device beneficially receives at least one of a third plurality of narrowband optical signals for routing through the optical power managed network node. The first plurality of narrowband optical signals beneficially comprises those of the second plurality of narrowband optical signals and the third plurality of narrowband optical signals that are routed through the optical power managed network node.

In accordance with still further aspects of the present invention, the optical power managed network node further beneficially comprises a controller for controlling the power of at least one of the third plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

In accordance with still further aspects of the present invention, the multiplexed polychromatic optical signal is preferably a first multiplexed polychromatic optical signal, and the optical power managed network node further beneficially comprises a demultiplexing device for separating a second multiplexed polychromatic optical signal into the second plurality of narrowband optical signals. The wavelength-selective optical power detector may beneficially detect the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal. Alternatively, the optical power managed network node may further beneficially comprise a second wavelength-selective optical power detector for detecting the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

In an alternative embodiment, the technique is realized as a method for processing dense wavelength division multiplexed signals in an optical power managed network node. The method comprises combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal, and then detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal. The method also comprises attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals. As in the first embodiment of the optical power managed network node described above, the

plurality of narrowband optical signals are beneficially attenuated, prior to being combined into the multiplexed polychromatic optical signal, so as to equalize the power in each of the plurality of narrowband optical signals.

5 In accordance with other aspects of the present invention, the power of the multiplexed polychromatic optical signal is beneficially adjustably amplified based upon the detected power of each of the plurality of narrowband optical signals.

10 In accordance with further aspects of the present invention, the plurality of narrowband optical signals is preferably a first plurality of narrowband optical signals, and a second plurality of narrowband optical signals is beneficially switched according to a predetermined signal routing scheme, wherein the second plurality of narrowband optical signals constitutes at least a portion of the first plurality of narrowband optical signals. Again, the second plurality of narrowband optical signals are beneficially switched such that the second plurality of narrowband optical signals are routed to either a local sub-node or through the optical power managed network node.

15 In accordance with still further aspects of the present invention, at least one of a third plurality of narrowband optical signals is beneficially received for routing through the optical power managed network node. Again, the first plurality of narrowband optical signals beneficially comprises those of the second plurality of narrowband optical signals and the third plurality of narrowband optical signals that are routed through the optical power managed network node.

20 In accordance with still further aspects of the present invention, the power of at least one of the third plurality of narrowband optical signals is beneficially controlled based upon the detected power of each of the plurality of narrowband optical signals.

25 In accordance with still further aspects of the present invention, the multiplexed polychromatic optical signal is preferably a first multiplexed polychromatic optical signal, and a second multiplexed polychromatic optical signal is beneficially separated into the second plurality of narrowband optical signals. The power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal can be beneficially detected

30

either separately or along with the power of each of the first plurality of narrowband optical signals.

The present invention will now be described in more detail with reference to exemplary embodiments thereof as shown in the appended drawings.

5

BRIEF DESCRIPTION OF THE DRAWINGS

In order to facilitate a fuller understanding of the present invention, reference is now made to the appended drawings. These drawings should not be construed as limiting the present invention, but are intended to be exemplary only.

10

Figure 1 is a schematic diagram of a preferred embodiment of an optical power managed network node for processing dense wavelength division multiplexed optical signals in accordance with the present invention.

Figure 2 is a schematic diagram of a preferred embodiment of an optical wavelength control technique in accordance with the present invention.

15

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENT(S)

Referring to Figure 1, there is shown a schematic diagram of a preferred embodiment of an optical power managed network node 10 for processing dense wavelength division multiplexed optical signals in accordance with the present invention. The optical power managed network node 10 comprises a demultiplexing device 12, a switching device 14, a plurality of variable optical attenuators 16, a multiplexing device 18, a variable optical amplifier or gain element 20, a wavelength-selective optical power detector/controller 22, a first plurality of optical receivers/transmitters 24, and a second plurality of optical transmitters/receivers 26. The optical power managed network node 10 operates, through its aforementioned constituent parts, as follows.

20

25

30

The demultiplexing device 12 receives a first dense wavelength division multiplexed (DWDM) polychromatic optical signal on an optical input fiber 28. The first DWDM polychromatic optical signal contains a first plurality of narrowband optical signals, each carrying a unique channel of transmitted data. The demultiplexing device 12 separates the first DWDM polychromatic optical signal into

the first plurality of narrowband optical signals contained therein and forwards each of the first plurality of narrowband optical signals to the switching device 14 along a corresponding plurality of optical fibers 30.

5 The switching device 14 switches the first plurality of narrowband optical signals according to some signal routing scheme. That is, each of the first plurality of narrowband optical signals either pass through the switching device 14 so as to be output from the switching device 14 on one of a plurality of optical fibers 32, or are "dropped" by the optical power managed network node 10, and hence from the network to which the optical power managed network node 10 is connected. Those
10 narrowband optical signals that are "dropped" by the optical power managed network node 10 are output from the switching device 14 on optical fibers 34, which are connected to the first plurality of optical receivers/transmitters 24. The first plurality of optical receivers/transmitters 24 transmit the narrowband optical signals received on optical fibers 34 to one or more sub-nodes (not shown) via output optical fibers 36.
15 Of course, the optical fibers 34 that carry the narrowband optical signals from the optical power managed network node 10 could extend all the way to the one or more sub-nodes (not shown), thereby alleviating the need for the first plurality of optical receivers/transmitters 24.

20 The second plurality of optical receivers/transmitters 26 may or may not be connected to the same sub-nodes as the first plurality of optical receivers/transmitters 24. In any event, the second plurality of optical receivers/transmitters 26 receive narrowband optical signals from one or more sub-nodes (not shown) on input optical fibers 38. The second plurality of optical receivers/transmitters 26 transmit the narrowband optical signals received on input optical fibers 38 to the switching device
25 14 via optical fibers 40. Of course, as with the optical fibers 34 that carry the narrowband optical signals from the optical power managed network node 10, the optical fibers 40 that carry the narrowband optical signals to the optical power managed network node 10 could extend all the way from the one or more sub-nodes (not shown), thereby alleviating the need for the second plurality of optical
30 receivers/transmitters 26.

- 10 -

The switching device 14 "adds" the narrowband optical signals received on optical fibers 40 to the network to which the optical power managed network node 10 is connected. That is, the switching device 14 includes the narrowband optical signals received on optical fibers 40 with those narrowband optical signals from the first plurality of narrowband optical signals that pass through the switching device 14 and are output from the switching device 14 on one of the plurality of optical fibers 32. Thus, the plurality of optical fibers 32 carry a second plurality of narrowband optical signals comprised of the narrowband optical signals from the first plurality of narrowband optical signals that pass through the switching device 14 (i.e., those of the first plurality of narrowband optical signals that are not "dropped" by the optical power managed network node 10), as well as the "added" narrowband optical signals received at the switching device 14 on optical fibers 40.

At this point it should be noted that the switching device 14 can be, for example, a switch matrix or some other type of fixed or dynamic optical signal switching element.

The plurality of optical fibers 32 carry the second plurality of narrowband optical signals to the plurality of variable optical attenuators 16. As described in more detail below, the plurality of variable optical attenuators 16 act to equalize the power level of each of the second plurality of narrowband optical signals based upon the detected power level of each of the second plurality of narrowband optical signals after they have been multiplexed by the multiplexing device 18 and amplified by the variable optical amplifier or gain element 20. Thus, at this point, suffice it to say that the plurality of variable optical attenuators 16 act to equalize the power level of each of the second plurality of narrowband optical signals prior to being multiplexed by the multiplexing device 18. The plurality of variable optical attenuators 16 thus provide an attenuated version of the second plurality of narrowband optical signals to the multiplexing device 18 via a plurality of optical fibers 42.

As mentioned above, the multiplexing device 18 combines the attenuated version of the second plurality of narrowband optical signals into a second dense wavelength division multiplexed (DWDM) polychromatic optical signal and forwards this second DWDM polychromatic optical signal to the variable optical amplifier or

gain element 20 on an optical output fiber 44. As described in more detail below, the variable optical amplifier or gain element 20 amplifies this second DWDM polychromatic optical signal based upon the detected power level of each of the second plurality of narrowband optical signals contained in the second DWDM polychromatic optical signal (i.e., after attenuation by the plurality of variable optical attenuators 16 and multiplexing by the multiplexing device 18). The variable optical amplifier or gain element 20 thus provides an amplified version of the second DWDM polychromatic optical signal on output optical fiber 46. At this point it should be noted that the variable optical amplifier or gain element 20 could be, for example, an erbium doped fiber amplifier (EDFA), an erbium doped waveguide amplifier (EDWA), a Raman amplifier, or some other type of variable optical amplifier or gain element.

The wavelength-selective optical power detector/controller 22 taps a portion of the amplified version of the second DWDM polychromatic optical signal being carried on output optical fiber 46 via an optical tap fiber 48 so as to detect the power level of each of the second plurality of narrowband optical signals contained in the second DWDM polychromatic optical signal (i.e., after attenuation by the plurality of variable optical attenuators 16 and multiplexing by the multiplexing device 18). One technique for accomplishing this power detection function is described in related U.S. Patent Application No. 09/578,721, filed May 26, 2000, which has previously been incorporated by reference herein in its entirety.

After determining the power level of each of the second plurality of narrowband optical signals contained in the second DWDM polychromatic optical signal (i.e., after attenuation by the plurality of variable optical attenuators 16 and multiplexing by the multiplexing device 18), the wavelength-selective optical power detector/controller 22 provides one or more first power control signals to the plurality of variable optical attenuators 16 on a first power control signal line/bus 50, and provides a second power control signal to the variable optical amplifier or gain element 20 on a second power control signal line/bus 52. These first and second power control signals allow the power level of the amplified version of the second DWDM polychromatic optical signal on output optical fiber 46 to be controlled such

- 12 -

that the amplified version of the second DWDM polychromatic optical signal on output optical fiber 46 is always at a constant power level. Thus, the optical power managed network node 10 always provides a constant power level DWDM polychromatic optical output signal. This constant power level DWDM polychromatic optical output signal provided by the optical power managed network node 10 is probably most beneficial when it matches the power level of the first DWDM polychromatic optical signal on the optical input fiber 28, thereby resulting in the optical power managed network node 10 having a zero decibel (dB) level loss. Thus, the present invention optical power managed network node 10 alleviates the need for manual network initialization procedures whenever additional optical signals are added to a network, existing optical signals are dropped from a network, or a network is otherwise reconfigured in some manner (e.g., an additional optical add/drop network node is added to a network, an existing optical add/drop network node is removed from a network, etc.).

At this point it should be noted that the wavelength-selective optical power detector/controller 22 may also provide a third power control signal to the second plurality of optical receivers/transmitters 26 on a third power control signal line/bus 54 so as to control the power level of the second plurality of optical receivers/transmitters 26 which transmit the narrowband optical signals received on input optical fibers 38 to the switching device 14 via optical fibers 40. This additional aspect of power level control in accordance with the present invention may be beneficial in that the second plurality of optical receivers/transmitters 26 may be of a lower power variety, thereby requiring less cost.

At this point it should be noted that the wavelength-selective optical power detector/controller 22 may also tap a portion of the first DWDM polychromatic optical signal being carried on optical input fiber 28 via an optical tap fiber 56 so as to detect the power level of each of the first plurality of narrowband optical signals contained in the first DWDM polychromatic optical signal. This additional aspect of power level control in accordance with the present invention may be beneficial in that the power level of each of the first plurality of narrowband optical signals contained in the first

DWDM polychromatic optical signal may be detected so as to determine if any failures have occurred in the network.

Referring to Figure 2, there is shown a schematic diagram of a preferred embodiment of an optical wavelength control system 60 in accordance with the present invention. The optical wavelength control system 60 comprises a central office 62, an optical cross-connect 64, an optical wavelength monitor 66, and a laser locking device 68. The optical wavelength control system 60 operates, through its aforementioned constituent parts, as follows.

The central office 62 receives and transmits a plurality of narrowband optical signals from and to the optical cross-connect via a plurality of optical fibers 76. The plurality of optical fibers 76 connect to a plurality of multiplexing/demultiplexing devices within the optical cross-connect 64. That is, the optical cross-connect 64 includes a first multiplexing/demultiplexing device 70, a second multiplexing/demultiplexing device 72, and a third multiplexing/demultiplexing device 74, each for receiving and transmitting the plurality of narrowband optical signals from and to the central office 62 via the plurality of optical fibers 76. The plurality of multiplexing/demultiplexing devices 70, 72, 74 within the optical cross-connect 64 perform multiplexing functions on the plurality of narrowband optical signals received from the central office 62 so as to generate dense wavelength division multiplexed (DWDM) polychromatic optical signals transmitted on optical fibers 78, 80, 82, respectively. The plurality of multiplexing/demultiplexing devices 70, 72, 74 within the optical cross-connect 64 also perform demultiplexing functions on DWDM polychromatic optical signals received on optical fibers 78, 80, 82, respectively, so as to generate the plurality of narrowband optical signals transmitted to the central office 62.

Similar to the wavelength-selective optical power detector/controller 22 of Figure 1, the optical wavelength monitor 66 of Figure 2 taps a portion of the DWDM polychromatic optical signals being carried on each of the optical fibers 78, 80, 82 via optical tap fibers 84, 86, 88, respectively, so as to detect the wavelength of each of the plurality of narrowband optical signals contained in all of the DWDM polychromatic optical signals. One technique for accomplishing this wavelength monitoring function

- 14 -

is described in related U.S. Patent Application No. 09/578,721, filed May 26, 2000, which has previously been incorporated by reference herein in its entirety.

5 The optical wavelength monitor 66 provides an indication of the wavelength of each of the plurality of narrowband optical signals contained in all of the DWDM polychromatic optical signals to the laser locking device 68 via one or more wavelength indicator lines 90. The laser locking device 68 in turn provides one or more laser control signals to the central office 62 via laser control lines 92. These laser control signals provide a mechanism for controlling the accuracy of the wavelengths of each of the plurality of narrowband optical signals transmitted from
10 the central office 62. Thus, the optical wavelength control system 60 insures that wavelength accuracy is maintained within the system.

The present invention is not to be limited in scope by the specific embodiments described herein. Indeed, various modifications of the present invention, in addition to those described herein, will be apparent to those of ordinary
15 skill in the art from the foregoing description and accompanying drawings. Thus, such modifications are intended to fall within the scope of the following appended claims. Further, although the present invention has been described herein in the context of a particular implementation in a particular environment for a particular purpose, those of ordinary skill in the art will recognize that its usefulness is not
20 limited thereto and that the present invention can be beneficially implemented in any number of environments for any number of purposes. Accordingly, the claims set forth below should be construed in view of the full breath and spirit of the present invention as disclosed herein.

- 15 -

CLAIMS

What is claimed is:

1. An optical power managed network node for processing dense wavelength division multiplexed signals comprising:

5 a dense wavelength division multiplexing device for combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal;

a wavelength-selective optical power detector for detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal; and

10 a plurality of attenuators for attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

2. The optical power managed network node as defined in claim 1, further comprising:

15 an adjustable power amplifier for adjustably amplifying the power of the multiplexed polychromatic optical signal based upon the detected power of each of the plurality of narrowband optical signals.

3. The optical power managed network node as defined in claim 1, wherein the at least one of the plurality of narrowband optical signals is attenuated so as to equalize the power in each of the plurality of narrowband optical signals.

20 4. The optical power managed network node as defined in claim 1, wherein the at least one of the plurality of narrowband optical signals is attenuated prior to being combined into the multiplexed polychromatic optical signal.

5. The optical power managed network node as defined in claim 1, wherein the plurality of narrowband optical signals is a first plurality of narrowband optical signals, further comprising:

25 a switching device for switching a second plurality of narrowband optical signals according to a predetermined signal routing scheme, wherein the second plurality of narrowband optical signals constitutes at least a portion of the first plurality of narrowband optical signals.

30

- 16 -

6. The optical power managed network node as defined in claim 5, wherein at least one of the second plurality of narrowband optical signals is switched such that the at least one switched narrowband optical signal is routed to a local sub-node.

5 7. The optical power managed network node as defined in claim 5, wherein at least one of the second plurality of narrowband optical signals is switched such that the at least one switched narrowband optical signal is routed through the optical power managed network node.

8. The optical power managed network node as defined in claim 7,
10 wherein the switching device receives at least one of a third plurality of narrowband optical signals for routing through the optical power managed network node.

9. The optical power managed network node as defined in claim 8, wherein the first plurality of narrowband optical signals comprises those of the second plurality of narrowband optical signals and the third plurality of narrowband optical
15 signals that are routed through the optical power managed network node.

10. The optical power managed network node as defined in claim 8, further comprising:

a controller for controlling the power of the at least one of the third plurality of narrowband optical signals based upon the detected power of each of the plurality of
20 narrowband optical signals.

11. The optical power managed network node as defined in claim 5, wherein the multiplexed polychromatic optical signal is a first multiplexed polychromatic optical signal, further comprising:

a demultiplexing device for separating a second multiplexed polychromatic
25 optical signal into the second plurality of narrowband optical signals.

12. The optical power managed network node as defined in claim 11, wherein the wavelength-selective optical power detector also detects the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

- 17 -

13. The optical power managed network node as defined in claim 11, wherein the wavelength-selective optical power detector is a first wavelength-selective optical power detector, further comprising:

5 a second wavelength-selective optical power detector for detecting the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

14. A method for processing dense wavelength division multiplexed signals in an optical power managed network node, the method comprising the steps of:

10 combining a plurality of narrowband optical signals into a multiplexed polychromatic optical signal;

detecting the power of each of the plurality of narrowband optical signals combined into the multiplexed polychromatic optical signal; and

15 attenuating the power of at least one of the plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

15. The method as defined in claim 14, further comprising the step of: adjustably amplifying the power of the multiplexed polychromatic optical signal based upon the detected power of each of the plurality of narrowband optical signals.

20 16. The method as defined in claim 14, wherein the at least one of the plurality of narrowband optical signals is attenuated so as to equalize the power in each of the plurality of narrowband optical signals.

25 17. The method as defined in claim 14, wherein the at least one of the plurality of narrowband optical signals is attenuated prior to being combined into the multiplexed polychromatic optical signal.

18. The method as defined in claim 14, wherein the plurality of narrowband optical signals is a first plurality of narrowband optical signals, further comprising the step of:

30 switching a second plurality of narrowband optical signals according to a predetermined signal routing scheme, wherein the second plurality of narrowband

optical signals constitutes at least a portion of the first plurality of narrowband optical signals.

5 19. The method as defined in claim 18, wherein at least one of the second plurality of narrowband optical signals is switched such that the at least one switched narrowband optical signal is routed to a local sub-node.

 20. The method as defined in claim 18, wherein at least one of the second plurality of narrowband optical signals is switched such that the at least one switched narrowband optical signal is routed through the optical power managed network node.

10 21. The method as defined in claim 20, further comprising the step of: receiving at least one of a third plurality of narrowband optical signals for routing through the optical power managed network node.

 22. The method as defined in claim 21, wherein the first plurality of narrowband optical signals comprises those of the second plurality of narrowband optical signals and the third plurality of narrowband optical signals that are routed
15 through the optical power managed network node.

 23. The method as defined in claim 21, further comprising the step of: controlling the power of the at least one of the third plurality of narrowband optical signals based upon the detected power of each of the plurality of narrowband optical signals.

20 24. The method as defined in claim 18, wherein the multiplexed polychromatic optical signal is a first multiplexed polychromatic optical signal, further comprising the step of:

 separating a second multiplexed polychromatic optical signal into the second plurality of narrowband optical signals.

25 25. The method as defined in claim 24, wherein the step of detecting includes detecting the power of each of the second plurality of narrowband optical signals contained within the second multiplexed polychromatic optical signal.

 26. The method as defined in claim 24, further comprising the step of: detecting the power of each of the second plurality of narrowband optical
30 signals contained within the second multiplexed polychromatic optical signal.

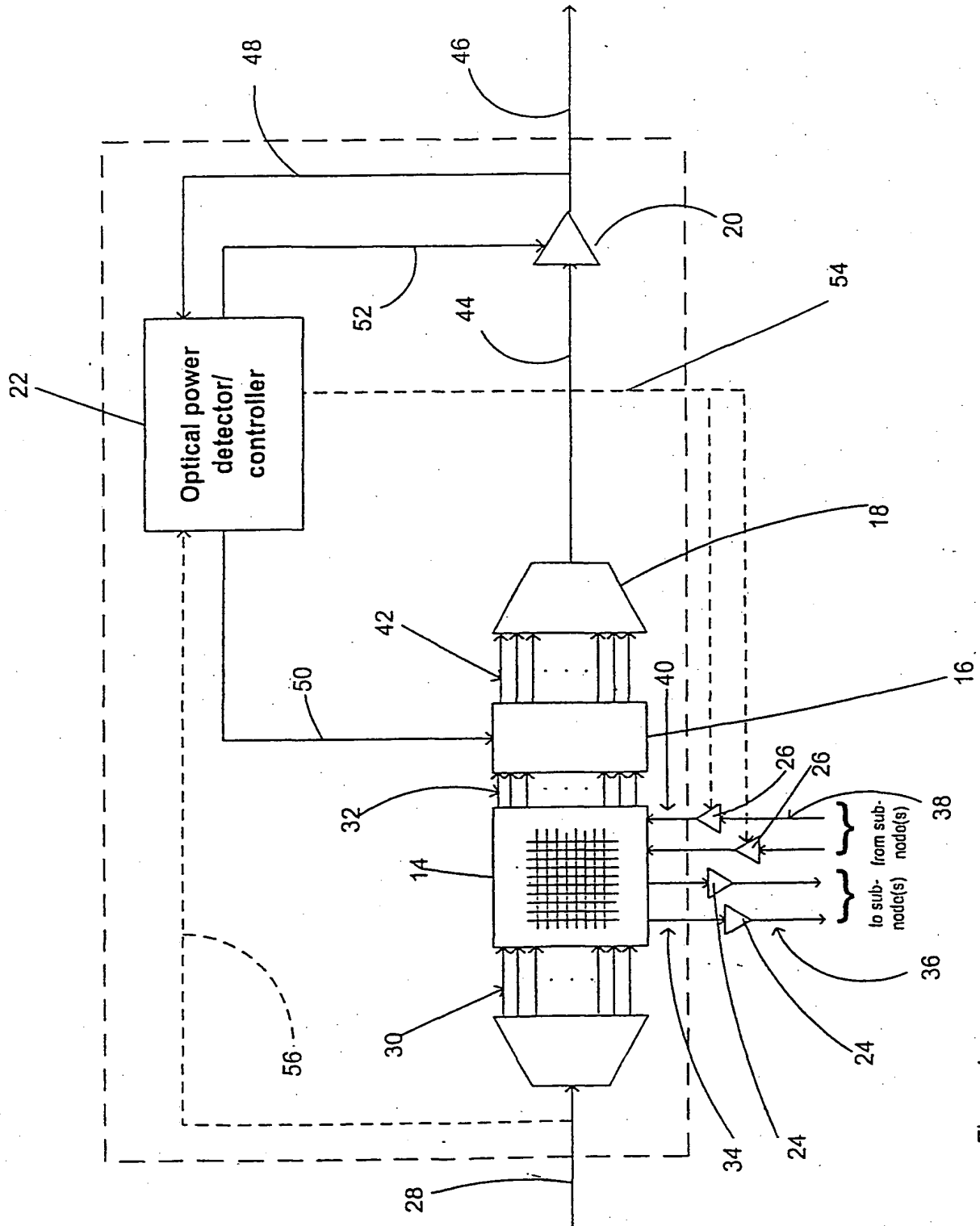


Figure 1

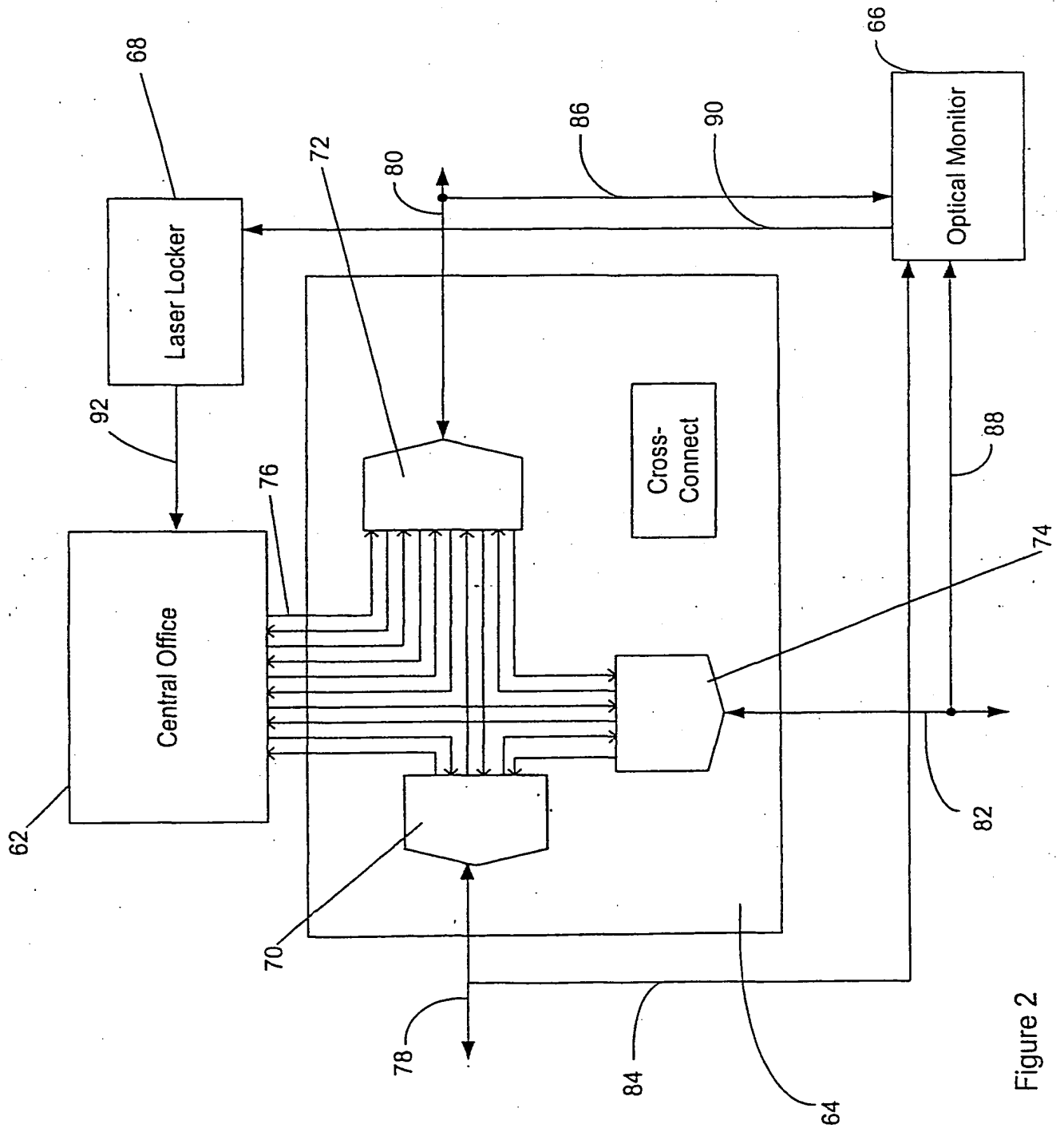


Figure 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/07034

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : Please See Extra Sheet.

US CL : 359/124, 161, 341; 385/27

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 359/124, 161, 341; 385/27

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONEElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST, WEST, optical power detector, attenuators

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 6,031,647 A (ROBERTS) 29 February 2000, Fig. 2, col. 5, lines 20-58.	1, 3, 4, 14, 16, 17 ----- 2, 5-9, 11-13, 15, 16-22, 24-26
X ----- Y	US 5,225,922 A (CHRAPLYVY et al) 06 July 1993, Fig. 2, col. 4, lines 16-56.	1, 3, 4, 14, 16, 17 ----- 2, 5-9, 11-13, 15, 16-22, 24-26
Y	US 5,812,710 A (SUGAYA) 22 September 1998, Figs. 2A and 2B, col. 4, lines 20-67.	2

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
B earlier document published on or after the international filing date	*Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z* document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means	
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

05 JULY 2001

Date of mailing of the international search report

24 AUG 2001

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer
LESLIE PASCAL

Telephone No. (703) 305-4700

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/07034

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,374,973 A (MAXHAM et al) 20 December 1994, Figs. 2 and 3, col. 3, lines 56-67, cols. 4 and 5, lines 1-67.	2
Y	US 5,959,749 A (DANAGHER et al) 28 September 1999, Fig. 2 col. 4, lines 45-67, col. 5, lines 1-67.	5-9, 11-13, 15, 16-22, 24-26
Y, P	US 6,040,933 A (KHALEGHI et al) 21 March 2000, Figs. 3 and 4, col. 6, lines 47-67, col. 7, lines 1-67, col. 8, lines 1-40.	10 and 23
Y, P	US 6,134,034 A (TERAHARA) 17 October 2000, Fig. 9, col. 9, lines 32-67.	10 and 23

Form PCT/ISA/210 (continuation of second sheet) (July 1998)★

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/07034

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (7):

H04J 14/00, 14/02; G02B 6/28; H01S 3/00; H04B 10/12, 14/00; G02F 1/39

This Page Blank (uspto)